

Evaluation of the NRL LWA Active Balun Prototype

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Abstract. This report described the laboratory evaluation of an active balun designed and built by Brian Hicks of the Naval Research Laboratory. Measurements include S-parameters and noise temperature versus frequency over the 10-200 MHz band.

1. Introduction

An active balun, based on the Mini-Circuits Gali-74 GaP HBT amplifier chip, was developed by Brian Hicks of the Naval Research Laboratory for use in Long Wavelength Array (LWA) prototyping activities. Three units (Nos. 1, 2, and 3) were evaluated at the NRAO Dynamic Spectroscopy Laboratory (DSL). A photograph of the balun is presented in Figure 1.

The nominal designed frequency band is 10-90 MHz. The design uses primarily surface mount components on an FR-4 substrate. A 180-degree hybrid junction, manufactured by Tele-Tech, Inc. (model HX-62A), is the power combining component of the balun. The supply voltage to the Gali-74 chips is controlled by an on-board voltage regulator. The bias circuit is isolated from the RF microstrip transmission line by an inductance.

Measurements of active balun stability, input and output match to 50 ohms, forward gain, common mode rejection, and noise temperature were performed at the DSL. These are reported in the subsequent sections of this report. Additional measurements are being planned for the near future that will include gain sensitivity with temperature and humidity, and intermodulation distortion. These will be reported in upcoming revisions of this document. The dc supply for all measurements was 15 volts at 165 mA (2.48 watts).

2. Stability

In the stability test the output port of the balun was connected to an HP 8593A spectrum analyzer operating from 1 MHz to 10 GHz. One of the input ports was terminated in 50 ohms while the other was connected to a tunable impedance. Tuning was accomplished through various combinations of a sliding short, a sliding tee terminated in resistive loads, and several lengths of coaxial line. Of the three amplifiers tested, only one side of balun No. 3 showed oscillation at 5.33 GHz while all others were unconditionally stable.

Examination of balun No. 3 under a microscope revealed no obvious abnormalities during assembly that would have led to this oscillation. Further-

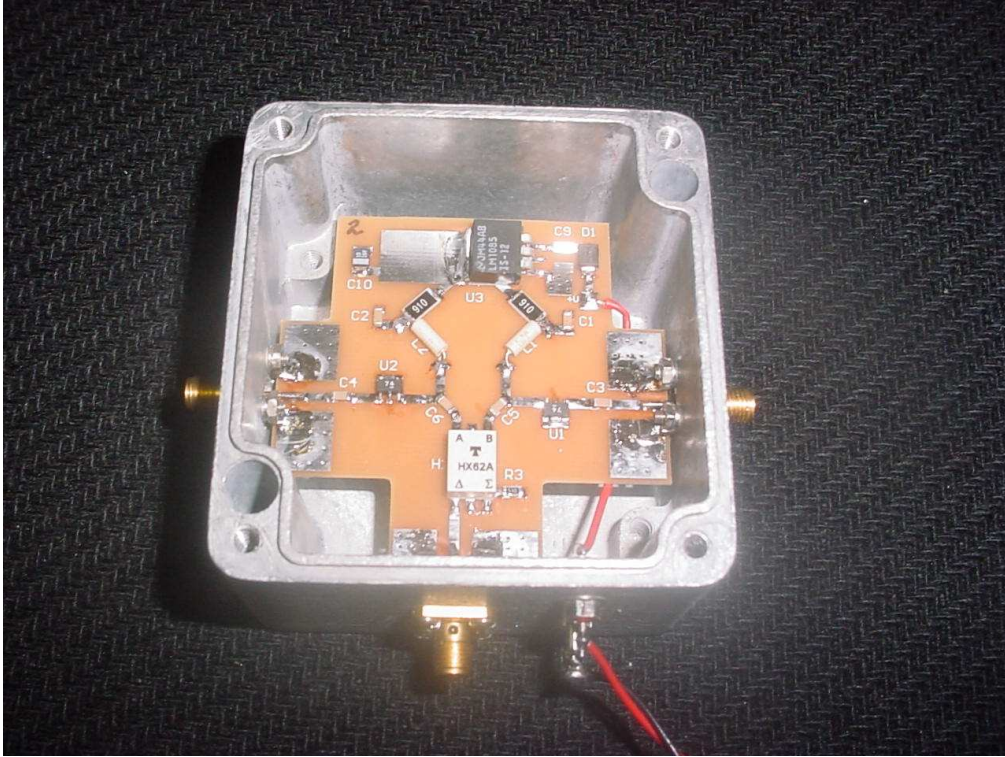


Figure 1. Photograph of active balun No. 2 with the cover removed. Input ports are on the left and right sides of the unit, as shown. The output port is at the bottom. Power supply leads are visible at the lower right

more, it was found that the oscillation was very sensitive to the cover position. The cover had to be tight with the side walls of the housing in order for the oscillation to occur. This indicates a cavity resonance which is providing a feedback path to the amplifier chip. Perhaps there is a very subtle defect to the circuit board on this side of the balun causing unwanted coupling to the cavity. The oscillation was quinched by attaching a two-inch square (approximately) piece of metalized mylar (3 mils thick) to the underside of the lid and therefore slightly lowering the Q of the cavity. With the mylar in place the amplifier is unconditionally stable.

3. Gain, Impedance Match, and Common Mode Rejection

Initial measurements were performed on both sides of the balun separately. All measurements utilized an HP 8753D vector network analyzer (VNA) calibrated in coaxial SMA connectors. Port two of the VNA was connected to the output of the balun. Excitation power at port one was set to -40 dBm to prevent any chance of saturation (dynamic range of the VNA is better than 80 dB). Frequency range these measurements was from 1-201 MHz.

All three baluns were evaluated in this manner. Results for balun No. 2 are shown here, but these results are very similar to those of the other baluns.

Port one of the VNA was connected to the left side (see Figure 1) input port while the right side port was terminated in 50 ohms. The S-parameter data was recorded. The input ports were then swapped and the S-parameters measured again. Figure 2a shows the gain or $\text{Mag}[S_{21}]$ versus frequency for the two sides of the balun while the $\text{Ang}[S_{21}]$ for both cases is compared in Figure 2b. With appropriate loss corrections applied, the gain agrees with the manufacturer's data sheet for the Gali-74. Figure 3a shows the input impedance plotted on a Smith Chart for both sides, while the output match, or $\text{Mag}[S_{22}]$, into 50 ohms is plotted in Figure 3b. Electrically, both sides of the balun are very well matched.

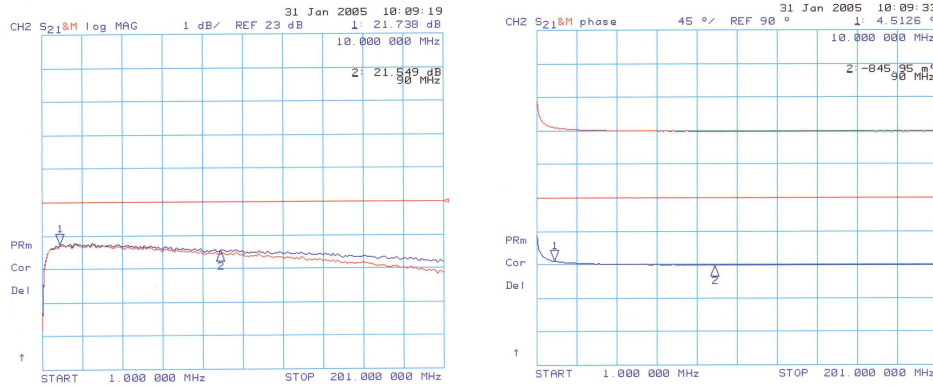


Figure 2. Plots showing the measurement of S_{21} versus frequency for both sides of the balun. a) $\text{Mag}[S_{21}]$ in dB, and b) $\text{Ang}[S_{21}]$ in deg.

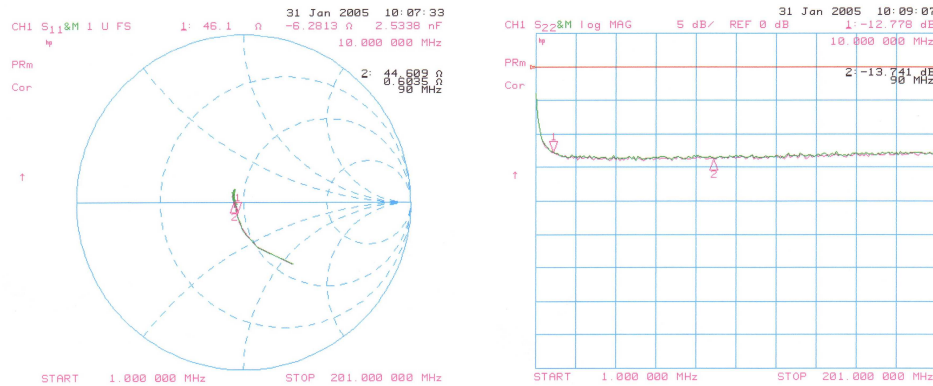


Figure 3. Plots showing the measurement of the input impedance and output match versus frequency for both sides of the balun. a) 50 ohm Smith displaying S_{11} , and b) $\text{Mag}[S_{22}]$ in dB.

The entire balun was evaluated next by using an external 180-degree hybrid (Tele-Tech Inc. HX62-A) to split the signal from VNA port one into the two input ports of the balun. The loss through the external hybrid was measured by the VNA to be 0.42 dB at 1 MHz to 0.47 dB at 201 MHz. These values

are better than the specification for the hybrid (loss = 1 dB) provided by the manufacturer. Measurement of $\text{Mag}[S_{21}]$ is shown in Figure 4a.

The hybrid was replaced with a Mini-Circuits in-phase power divider model PSC 2-1 for measurement of the common-mode rejection. Loss through this circuit was measured by the VNA to be 0.14 dB at 1 MHz and 0.50 dB at 201 MHz meeting the manufacturer's specification for this component. Phase balance is within 3 degrees. Figure 4b shows the common-mode rejection which is better than 44 dB at the output of the balun over the 10-90 MHz band.

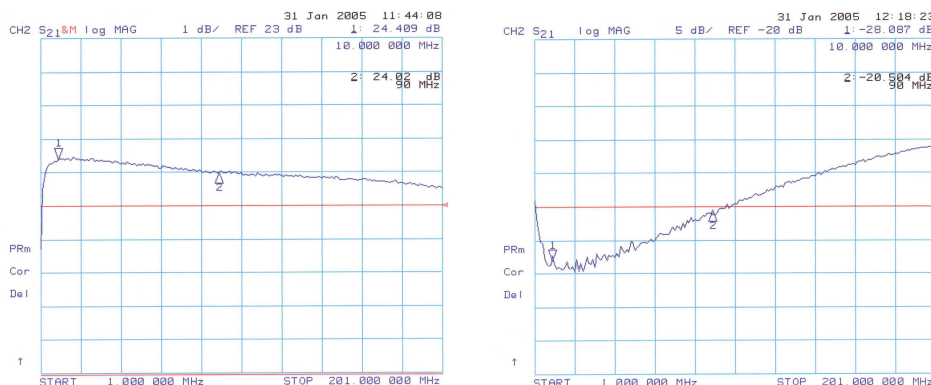


Figure 4. Plots of measured gain versus frequency for the entire balun. a) $\text{Mag}[S_{21}]$ in dB for balanced-mode operation, and b) $\text{Mag}[S_{21}]$ in dB for common-mode operation.

4. Noise Temperature

The noise temperature of the entire balun at ambient room temperature (about 25°C) was measured over the 10-200 MHz band using an Agilent N8973A and HP 346C calibrated noise diode. The external 180-degree hybrid was used in this measurement and the results were corrected with appropriate loss compensation. Figure 5 presents the measured noise temperature versus frequency. The average value of 250 K over the 10-90 MHz band is approximately that of the typical value provided by the manufacturer (NF=2.7 dB).

5. Gain versus Ambient Temperature

This measurement will be conducted in the near future. Results will be presented here.

6. Gain versus Humidity

This measurement will be conducted in the near future. Results will be presented here.

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Mkr1	10 MHz	246.100 K	25.072 dB
Mkr2	89.743 MHz	249.436 K	24.428 dB

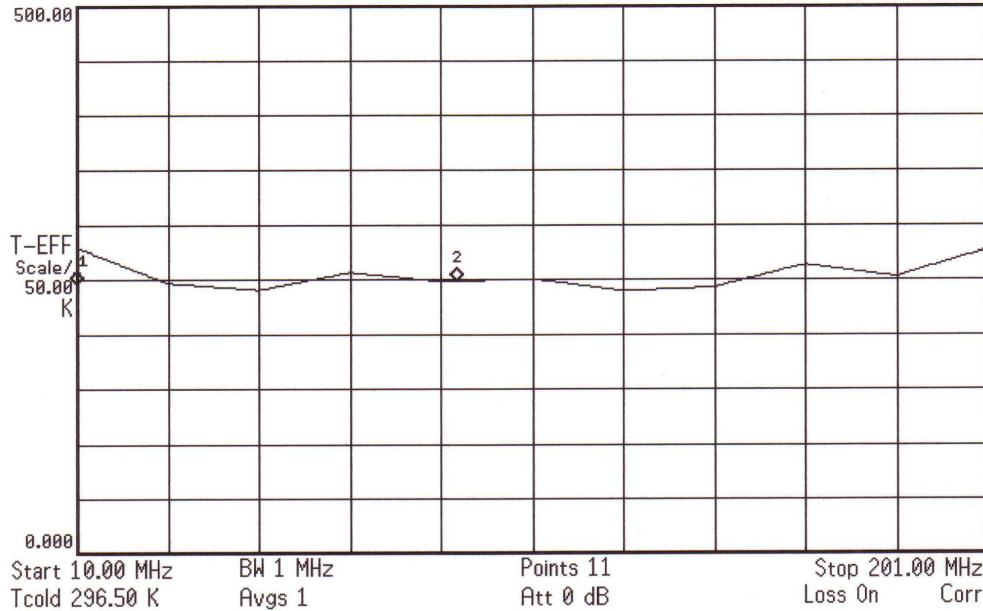


Figure 5. Plot of measured noise temperature versus frequency for the entire balun. Test fixture corrections applied.

7. Intermodulation Distortion Tests

This measurement will be conducted in the near future. Results will be presented here.

8. Discussions and Recommendations

This balun operates over the 10-90 MHz band and provides 24.5 dB gain with a noise temperature of approximately 250 K when the input is terminated in 50 ohms. These values are similar to those provided by the amplifier chip manufacturer thus indicating that amplifier's performance is not compromised by the balun design.

The amplifier has demonstrated unconditional stability in this configuration, but experience with the Gali-74 indicates that it's stability is very sensitive to the inductance between the chip ground tab and the RF circuit ground of the PC board. One chip (out of the six evaluated here that make up the three baluns) was found to oscillate at 5.33 GHz when the balun input port was subjected to a narrow range of input impedances far removed from 50 ohms. As a precaution, it is suggested that an inexpensive absorber be attached to the

underside of the balun's cover if a housing of this size is used in the final version. Note that this material has no effect on desired balun performance.

One concern is the relatively high value for $\text{Mag}[S_{22}]$ (output) which is on the order of -13 dB when all ports of the balun are terminated in 50 ohms. Measurements on the hybrid indicate that it is better than -25 dB over the 10-90 MHz band thus implying that the mismatch at the output of the balun is due to either the chip's internal circuit or the bias circuit. A value smaller than -20 dB should be attained. It is suggested that the bias circuit be evaluated separately from the chip and improved if it is found to be significantly loading the 50 ohm microstrip transmission line.

A mismatch at the balun's output port can lead to undesired ripples in the receiver's passband thus making station element power combining difficult to achieve over the 10-90 MHz bandwidth. This is further complicated by the fact that the output match is strongly affected by the balun's input termination. In other words, the dipole feed-point impedance will affect the balun's output match as a function of frequency. It should also be noted that the balun's noise temperature versus frequency will be affected by the input port termination impedance.

Based on the above measurements, I recommended that this balun be used for LWA prototyping. However, future improvements to the balun should focus on the noise temperature and the output match. A smaller, more compact package should also be designed.